MULTI-SCALE COMPUTATIONAL MODELING OF CARDIAC ELECTRO-MECHANICAL COUPLING: FROM ION CHANNELS TO TISSUE MECHANICS

JOAKIM SUNDNES*, ASLAK TVEITO‡

*Simula Research Laboratory, Oslo, Norway and
Department of Informatics, University of Oslo, Norway
sundnes@simula.no

‡Simula Research Laboratory, Oslo, Norway
aslak@simula.no

ABSTRACT

The coordinated contraction of the heart results from a complex interaction between electrophysiology and mechanics, readily assessed on the organ-scale in terms of electrical signal conduction and motion, but driven by electro-chemo-mechanical interactions at the scale of individual proteins. Existing computational models rely on extensive volume averaging for bridging these highly disparate scales, which limit their ability to study the coupling between molecular perturbations and tissue behavior. Recent advances have highlighted the need for accurately capturing the details on the nanoscale, see, e.g., [1, 2], but the crucial coupling of electrophysiology and mechanics at this scale remains underexplored. This session addresses multiscale models of cardiac electromechanical coupling, with particular emphasis on the coupling of mechanisms at sub-cellular scale and how they translate to tissue and organ function. Topics of particular interest include:

- Nanoscale electrodiffusion and its coupling to local calcium dynamics and contractile machinery.
- Spatially explicit Monte Carlo and finite element (FE) models of sarcomere mechanics.
- The Extracellular-Membrane-Intracellular (EMI) framework for cell-level resolution in electrophysiology and mechanics.
- Multi-scale modeling of excitation-contraction (EC) coupling in health and disease.
- Efficient solvers and splitting methods for complex electro-mechanical systems.

REFERENCES

[1] Jæger, K. H., and Tveito, A. Electrodiffusion dynamics in the cardiomyocyte dyad at nano-scale resolution using the Poisson-Nernst-Planck (PNP) equations. *PLoS computational biology*, 21(6), 2025.

[2] Telle, Å., Trotter, J. D., Cai, X., Finsberg, H., Kuchta, M., Sundnes, J., and Wall, S. T. A cell-based framework for modeling cardiac mechanics. *Biomechanics and Modeling in Mechanobiology*, 22, 515-539, 2023.